BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Initial Thrust Mistrim and c.g. Motion Effects on Translunar and Transearth Midcourse Correction Maneuvers - Case 310

DATE: August 22, 1968

FROM: F. La Piana

ABSTRACT

A computer program simulation of the command module digital autopilot, command module/lunar excursion module rotational dynamics and the command module guidance and navigation system was made. Translunar and transearth midcourse correction maneuvers using the service propulsion system were simulated for the primary purpose of generating cross axis (error) velocity and attitude histories as a result of initial thrust mistrim and c.g. motion during the burn. Two guidance schemes were evaluated. Open loop guidance, where the velocity to be gained is held fixed and time of burn is externally controlled, and closed loop guidance where the velocity to be gained is the time varying difference between the required velocity and the vehicle velocity as computed by the command module guidance computer.

For the 3σ values of mistrim used, the maximum attitude deviation under any condition was 6.5°. For open loop guidance, translunar error velocity maximum (and terminal value) was 9 fps and transearth was 18 fps. For closed loop guidance, the maximum translunar value is 5.5 fps and trans-earth is 12 fps, the terminal values approaching zero for burn times of 14 seconds or longer.

(NASA-CR-97694) INITIAL THRUST MISTRIM AND C.G. MOTION EFFECTS ON TRANSLUNAR AND TRANSEARTH MIDCOURSE CORRECTION MANEUVERS (Bellcomm, Inc.) 30 p

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MEMORANDUM FOR FILE

1. INTRODUCTION

The purpose of this study was to evaluate the effects of initial thrust mistrim and center of gravity motion on translunar and transearth midcourse correction maneuvers. These effects are the errors in vehicle attitude and cross-axis velocity for a desired velocity increment along the longitudinal axis of the vehicle.

The Digital Autopilot (DAP), the command module guidance system and the vehicle rigid body dynamics simulation routines were built and added to the Bellcomm Powered Flight Performance Simulator Computer Program for this study. Vehicle parameters and reference trajectory data utilized are those for the AS-504 mission and were taken from references 2, 3, 5, and 7.

Either onboard Lambert calculations for velocity required or external delta velocity type burns are used for these Service Propulsion System maneuvers. Simulations with both open loop and closed loop guidance were used. Ideal guidance system alignment and operation is assumed in order to isolate the effects due to the situations under investigation.

2. SIMULATION METHODS AND ASSUMPTIONS

a. Guidance System

For the open loop guidance case an inertially fixed direction of the velocity to be gained was used, therefore actual vehicle velocity did not enter into the steering equation. Either a fixed time of burn or predetermined velocity change is used for external thrust termination control. The technique used to achieve this in the simulation was to hold velocity to be gained ($\overline{VG}$) at a unity value along the initial vehicle longitudinal axis and calculate the guidance computer command with the familiar cross product steering equation:

$$\overline{W}_c = K \frac{\overline{VG} \times \left[c\left(\dot{\overline{VR}} - \overline{g}\right) - \overline{a}_T\right]}{\left|\overline{VG}\right| \left|c\left(\dot{\overline{VR}} - \overline{g}\right) - \overline{a}_T\right|} \qquad \text{(Eq. 1)}$$

In order to isolate the cross-axis (error) attitude and velocity due to initial mistrim and c.g. motion, the "curvative constant C" was set as zero for all runs. Equation 1 then reduced to

$$W_c = K \frac{\overline{VG} \times \left[-\overline{a}_T\right]}{\left|\overline{VG}\right| \ \left|a_T\right|} \qquad \text{(Eq. 2)}$$

Where a_T is the thrust acceleration and K is a gain factor.

Since VG and $\overline{a}_T$ are both of constant magnitude, the steering command ($\overline{W}_c$) is a function solely of the sine of the angle between them, and is independent of the "time to go" for the burn. Holding $\overline{VG}$ at constant direction and magnitude causes the guidance system to operate as a cross-axis acceleration nulling control loop since it does not attempt to null cross-axis (error) velocities. This simulates the condition desired; open loop guidance with constant $\overline{VG}$ and using the guidance system accelerometers for direction control. Thrust is assumed terminated by an external means. This is essentially a manual type of maneuver.

For closed loop guidance simulations, it was desired to represent a midcourse correction maneuver under automatic control of the CM guidance system. Equation 2 is also used, however $\overline{VG}$ is not a constant input quantity, but is recomputed each guidance cycle by the CM computer:

$$\overline{VG} = \overline{VR} - \overline{V} \qquad \text{(Eq. 3)}$$

Where $\overline{VR}$ is the end of burn velocity required and $\overline{V}$ is the present vehicle velocity. $\overline{VG}$ now includes any cross-axis (error) velocity present and the guidance system attempts to null it out. For purposes of this simulation, $\overline{VR}$ was computed using Lambert's technique based on a target aim point vector. For the translunar (TL) case, position and velocity at TLI plus five hours were propagated forward to TLI plus ten hours, using a Bellcomm Kepler orbit computer program, to get the aim point. For the transearth (TE) MCC, the target aim point was found by propagating the state vector at TEI plus four hours to TEI plus ten hours. AS-504 input data for this procedure was extracted from reference 2, as were the vehicle thrust and mass parameters used in this study.

b. Digital Autopilot

The DAP simulation added to the Bellcomm Powered Flight Performance Simulation computer program was taken from the Sundisk GSOP and includes all significant effects. The DAP start-up delay of .675 seconds and the start of guidance system signal acceptance at four seconds are features included. Also simulated for closed loop cases is the termination of input steering signals at four seconds prior to the computed "end of burn" time. This was determined by using the "time to go" (TGO) algorithm as it will be implemented in the CM computer.

$$TGO = \frac{-\overline{VG} \cdot \overline{I}_{\Delta VG}}{\left|\frac{\Delta\overline{VG}}{\Delta T}\right|}\left[1 + \frac{\overline{VG} \cdot \overline{I}_{\Delta VG}}{2\ VE}\right] - TDECAY \qquad \text{(Eq. 4)}$$

(From Reference 5)

Where $\overline{VG}$ and $\overline{I}_{\Delta VG}$ are the velocity to be gained and its' direction of unit change in one guidance cycle respectively, ΔT is the guidance system cycle time and VE is the engine exhaust velocity. TDECAY is the thrust tail-off correction factor, zero for this analysis.

Figure 1 is the schematic of the DAP as implemented. The $\overline{W}_c'/\overline{W}_c$ transfer function is simply the K of the cross-product steering equation. The loop containing CORFR and REPFR is the thrust misalignment corrector loop of the DAP. CORFR is a single shot corrector that is designed to remove the initial thrust mistrim cross-axis velocity effects. REPFR is a repetitive corrector to track and correct for the c.g. movement due to propellant expenditure during the SPS burns. A detailed description of the DAP schematic is included as Appendix 1.

c. Vehicle Parameters

The basic thrust and mass parameters used are those specified in reference 2. Mass used at TL MCC start was 2836.9 slugs and at TE MCC start 788.3 slugs. Thrust of the SPS engine was taken as 20,000 pounds in all cases. Additional vehicle data was provided by reference 4. For both the TL and TE midcourse correction maneuvers; center of gravity location, inertias, and thrust lever arm data was extracted in tabular form from reference 7.

Initial mistrim data was provided by data and equations in reference 1. Values used in this analysis are:

TL MCC, 3σ mistrim = 1.21° pitch and yaw

TE MCC, 3σ mistrim = 1.73° pitch and yaw

These values of mistrim include the contributions of the thrust vector control system error sources and the center of mass location uncertainty.

3. RESULTS

Graphs 1 through 16 are the attitude and cross-axis velocity time histories for each of the vehicles for both open loop and closed loop guidance.

For all cases the velocity to be gained is along the roll axis, any cross-axis velocity (pitch or yaw) is an error velocity due to the initial mistrim or c.g. motion.

The closed loop guidance velocity graphs all exhibit the characteristic profile of the cross product steering law where the $\frac{\overline{VG}}{|\overline{VG}|}$ term causes cross axis velocity errors (negative of $\overline{VG}$ components) to be weighted as a function of the downrange component of VG (or TGO). This scheme is an application of the technique of steering such that all three components of $\overline{VG}$ reach zero simultaneously.

Graphs 1 through 4 are the open loop guidance, pitch and yaw, attitude and velocity time histories for the translunar (CSM/LM) vehicle configuration. Comparative curves for $\pm 3\sigma$ ($\pm 1.21°$) and $\pm 1°$ show that peak values of attitude deviation and cross-axis velocity are directly proportional to the initial mistrim magnitude, proving that linear extrapolation is valid in the region under investigation. The DAP capability to control vehicle attitude is demonstrated in graphs 1 and 3. The result of using open loop velocity guidance is shown in the steady state cross axis velocity of graphs 2 and 4. It is significant to note (as evidenced by the 0° mistrim curves) that the c.g. motion is much more pronounced along the pitch than the yaw directions and that the position and velocity curves are quite symmetrical about the 0° mistrim line.

Graphs 5 through 8 are the corresponding open loop curves for the transearth (CSM) configuration and illustrate the much faster DAP system attitude control response time possible through the use of a simpler filter and higher gain with this more rigid vehicle. The c.g. motion is much greater along the yaw than the pitch direction of the CSM vehicle.

Graphs 9 through 16 are the closed loop velocity guidance versions of graphs 1 through 8 with burn times of 14 and 20 seconds. The comparison of graphs 1, 3, 5 and 7 with graphs 9, 11, 13 and 15 respectively shows the minor attitude history changes of open loop versus closed loop cases. Of significance is the cross-axis velocity comparisons of graphs 10, 12, 14 and 16 with 2, 4, 6 and 8 respectively. Graphs 10 and 12 show the failure of the low gain system used for the translunar MCC to null the cross axis velocity for a 14 second burn. Graphs 14 and 16 show that with the higher system gain usable with the CSM only that the cross axis velocity matches the 0° mistrim case for burns of 14 seconds or greater.

The design of the DAP system is such that steering signals are not accepted before 3.828 seconds after engine ignition. For purposes of the simulations this was increased to 4 seconds to include ignition time uncertainty and thrust build up effects. The system also includes the rejection of any new steering signals when the TGO is less than 4 seconds. This is intended to preclude large steering commands as VG approaches zero. In the closed loop simulation (where TGO is used) these features have the effect that, for any SPS burn of less than 8 seconds, the guidance loop is not closed. Attitude and cross-axis velocity data for burns of any length up to 8 seconds can be taken from the open loop curves.

Graphs 9 through 16 are plotted for burn times of 14 and 20 seconds. These curves belong to a family for which time of burn (TOB) is the parameter and the locus of the end points the significant feature if end of burn conditions (as a function of time of burn) is the closed loop parameter of interest. Graphs 1 through 8 are valid for any TOB shown, since for open loop velocity guidance TOB is not a parameter.

SUMMARY AND CONCLUSIONS

Open loop guidance (external $\overline{VG}$ direction and TOB specified) SPS MCC maneuvers with 3σ mistrim values of any burn duration produce peak attitude errors of up to 6.5° which are damped out by the DAP. Peak velocity errors for the CSM/LM (translunar MCC) are 9 fps (pitch) and 8 fps (yaw) which stabilize at or near the maximum. For the CSM (transearth MCC) velocity error peaks of 12 fps (pitch) and 18 fps (yaw) are reached, but stabilization does not occur (especially in yaw) due to the large effects of c.g. motion.

Closed loop guidance does not produce extensive differences in the attitude history since attitude is primarily under control of the DAP which operates in either the closed loop or open loop case. Velocity errors are held to lower peak values of 5.5 fps and 5 fps for translunar pitch and yaw and 9 fps and 12 fps for transearth pitch and yaw respectively. Of greater importance is the ability of the system to null velocity errors by the end of CSM burns as short as 14 seconds. Slightly longer burns for the CSM/LM configuration will produce similiar nulling results.

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2012-FL-bjw

Attachments
Appendix 1
References

16 Graphs
1 Figure

APPENDIX 1

The CM TVC Digital Autopilot (DAP) system software is included in the mission 205 AGC program, SUNDISK. The modifications made to the Bellcomm PFPS computer program include simulation of the software and the necessary hardware which comprise the DAP system. This includes the pitch and yaw DAP channels, rigid body rotational dynamics and the links and coordinate system rotational matrices necessary to complete the DAP and guidance loops.

The basic inputs to the DAP simulation are vehicle mass, thrust and commanded rotation rates from the cross-product steering equations. The outputs are vehicle attitude, turning rates, motor deflections and the thrust-to-platform coordinate system rotation matrix. The latter is used in the simulation of IMU platform sensed accelerations in the guidance loop.

Since the roll control system uses a separate and different DAP, it is not included in this modification. Roll is assumed stabilized at the aligned position (0°) where it does not affect the thrust direction or guidance equations. The DAP starts functioning in a stabilization mode at .675 seconds after engine ignition. At ignition plus 3.828 seconds steering signals are accepted from the guidance system. Steering stops at 4 seconds before the end of the burn.

The DAP loop is cycled every .040 or .080 seconds, depending on the vehicle configuration - the guidance loop every 2 seconds.

Calculations are made alternately for pitch and yaw throughout the DAP loop. The vector notation will be dropped, with the understanding that the appropriate pitch or yaw data is used as required. If the time-of-burn is less than .675 seconds, E is not calculated, simulating the not yet activated DAP system.

$\overline{W}_c'$ is the scaled commanded angular rate (in body coordinates) input to the DAP. The transfer functions for each schematic block are listed.

APPENDIX 1 (Continued)

a. The rate error, E, is the difference between the commanded value and the achieved rate:

$$E = \overline{W}'_c - \overline{W}_{BR}$$

b. The rate error is integrated then limited

$$IE = \int E dt = IE + E(\Delta t)$$

$$\Theta = IE \; ; \; |IE| \leq 45°$$

c. Two different filters are used, a first order filter for the CSM and a seventh order filter for the CSM/LM. Using the standard Z notation to designate digital computation intervals, the first order filter is:

$$\delta = KA_0\Theta + Z^{-1}(KA_1\Theta - B_1\,\delta)$$

Where

$$A_o = 1$$

$$A_1 = -.98$$

$$B_1 = -.64$$

and the seventh order filter is:

$$\delta = K\Big[C_1\Theta + Z^{-1}\Big(C_2\Theta - D_1\delta + Z^{-1}\Big(C_3\Theta - D_2\delta + Z^{-1}\Big(C_4\Theta - D_3\delta + Z^{-1}\Big(C_5\Theta - D_4\delta + Z^{-1}\Big(C_6\Theta - D_5\delta + Z^{-1}\Big(C_7\Theta - D_6\delta + Z^{-1}\Big(C_8\Theta\Big)\Big)\Big)\Big)\Big)\Big)\Big)\Big]$$

where the coefficients in Double Precision are:

$$C_1 = 1.$$

$$C_2 = -.2970947265625E1$$

$$C_3 = +.3194824218750E1$$

APPENDIX 1 (Continued)

C_4 = -.40966796875E0

C_5 = -.2578125E1

C_6 = +.2962890625E1

C_7 = -.151025390625E1

C_8 = +.3125E0

D_1 = +.4779897689790E1

D_2 = -.944527631998E1

D_3 = +.98593475222E1

D_4 = -.5723181128502E1

D_5 = +.1748475015163E1

D_6 = -.2193333506575E0

d. Simulating the CMC fixed word length accuracy limitations, the output of the filter is quantized to $\frac{1}{42.15}$ degree.

e. The thrust misalignment corrector (TMC) loop consists of a limiter (±6°), a filter:

DPBAR = .00995 (DELC) +Z^{-1}(.99005 DPBAR)

A "one-shot" corrector

ACTOFF = Z^{-1}(ACTOFFT) +CORFR (DPBAR -Z^{-1}(ACTOFF))

and a repetitive corrector, which is used every 1/2 second after the 'one shot'.

ACTOFF = Z^{-1}(ACTOFF) + REPFR (DPBAR -Z^{-1}(ACTOFF))

f. The output from the TMC loop (δ_c') is limited to $\pm$ 4.5° and used to form the thrust deflection (engine bell) actuator command, δ_{act}:

δ_{act} = Initial Conditions + Bias if TOB <.675 sec

$\delta_{act} = \delta_c'$ + Bias if TOB $\geq$.675 sec

g. Using a table look-up, with MASS as the input parameter, and interpolating; values of motor to C.G. lever arm (LX), C.G. location offset along the body axes (C.G.) and moment of inertia (I) are found.

The body angular acceleration $\dot{W}$ and rate W are computed using thrust (T)

$$\dot{W}_B = - \frac{T\,(LX(\delta_{act}) \pm C.G.)}{I}$$

$$W_B = Z^{-1}(W_B) + \frac{\dot{W}_B + Z^{-1}(\dot{W}_B)}{2}\,\Delta t$$

h. The gimbal angle rate (W_{GIM}) is computed from the body rate and the gimbal angles are integrated to determine the new gimbal angles which are used in the guidance computations.

i. The gimbal rates are reconstructed from the gimbal angle changes, simulating the action of the CM computer, these are then converted to body rates (W_{BR}) to close the DAP loop.

REFERENCES

1. NASA Memorandum #EG23-67-193, Initial Uncertainty in the SPS Thrust Vector Direction Due to Random Errors, by EG 23/Emory E. Smith, Jr., AST Dynamical Systems Section, March 1, 1968.

2. NASA Memorandum, AS-504A Preliminary Spacecraft Reference Trajectory, Volumes I and II, July 1, 1966, Manned Spacecraft Center, Houston, Texas.

3. MIT/IL, Space Guidance Analysis Memorandum #18-67, Performance of the Thrust Vector Control System for the CSM and CSM/LEM Configurations, October 13, 1967

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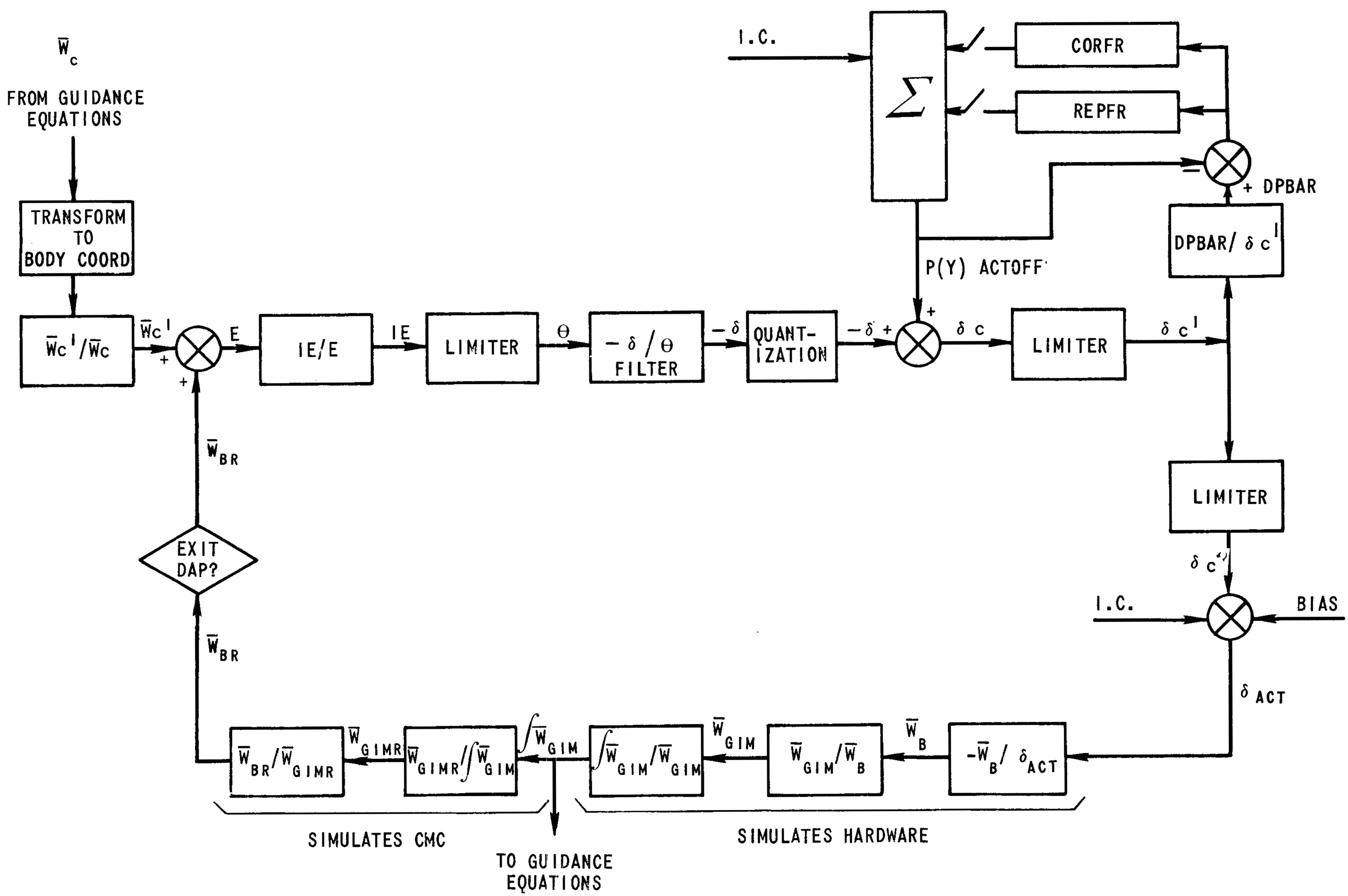
5. MIT/IL, Flight 258 Memorandum #59, Recent TVC DAP Changes, by A. Engel, August 21, 1967, Revision 1 to above, dated November 17, 1967 and Revision 2 to above, dated December, 28, 1967.

6. Bellcomm Memorandum for File, Rotational Dynamics Simulation Capability for Bellcomm PFPS Computer Program, from F. La Piana.

7. MIT/IL, 106 Data File, Machine listing received from R. Schlundt.



W̄c
FROM GUIDANCE EQUATIONS
TRANSFORM TO BODY COORD
W̄c'/W̄c
W̄c'
E
IE/E
IE
LIMITER
θ
−δ/θ FILTER
−δ
QUANT-IZATION
−δ'
I.C.
Σ
CORFR
REPFR
P(Y) ACTOFF'
δc
LIMITER
δc'
DPBAR/δc'
DPBAR
LIMITER
δc''
I.C.
BIAS
δ ACT
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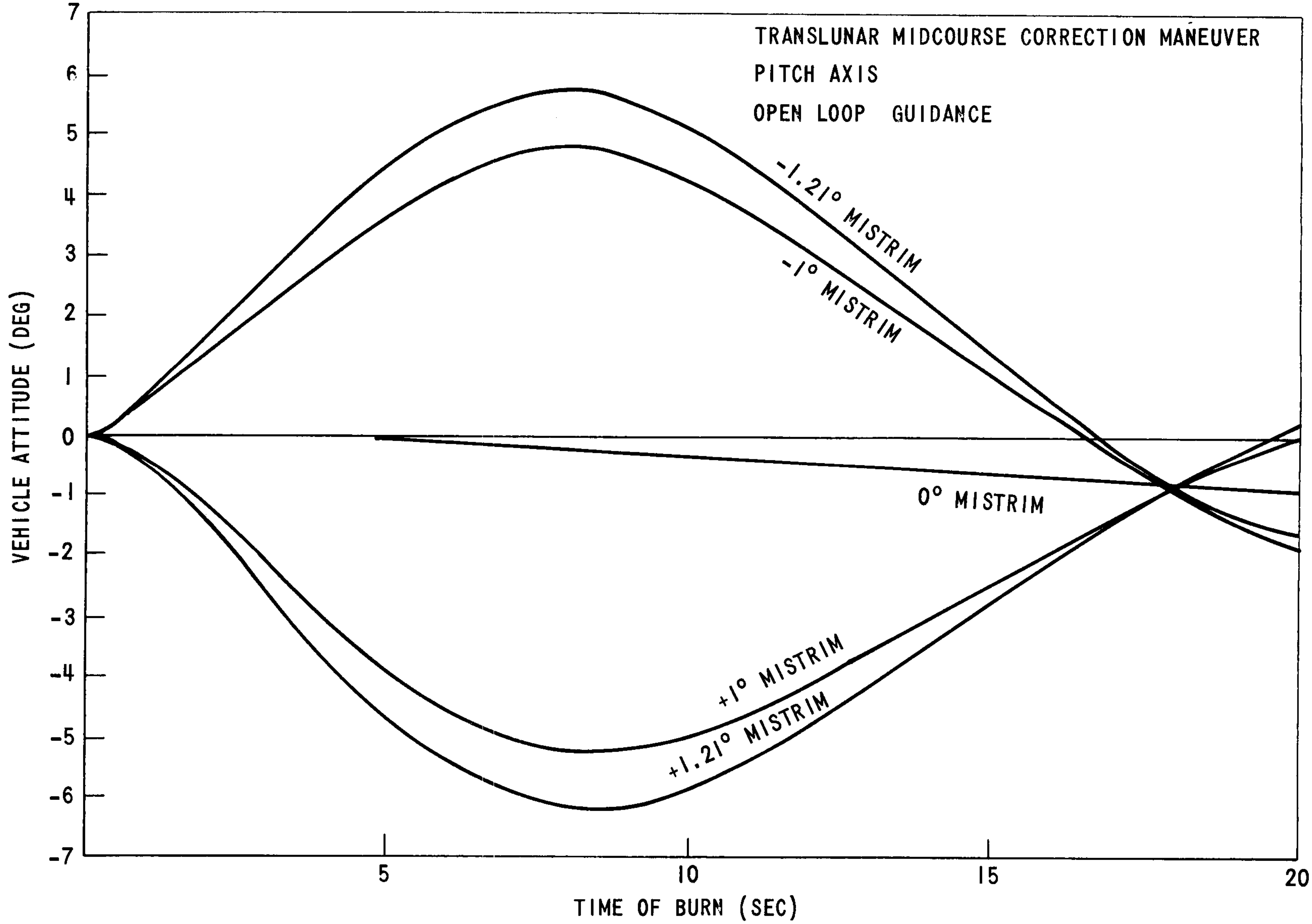
W̄B
W̄GIM/W̄B
W̄GIM
∫W̄GIM/W̄GIM
∫W̄GIM
W̄GIMR/∫W̄GIM
W̄GIMR
W̄BR/W̄GIMR
W̄BR
EXIT DAP?
W̄BR
SIMULATES CMC
TO GUIDANCE EQUATIONS
SIMULATES HARDWARE

FIGURE 1


TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
OPEN LOOP GUIDANCE
-1.21° MISTRIM
-1° MISTRIM
0° MISTRIM
+1° MISTRIM
+1.21° MISTRIM
VEHICLE ATTITUDE (DEG)
TIME OF BURN (SEC)
7
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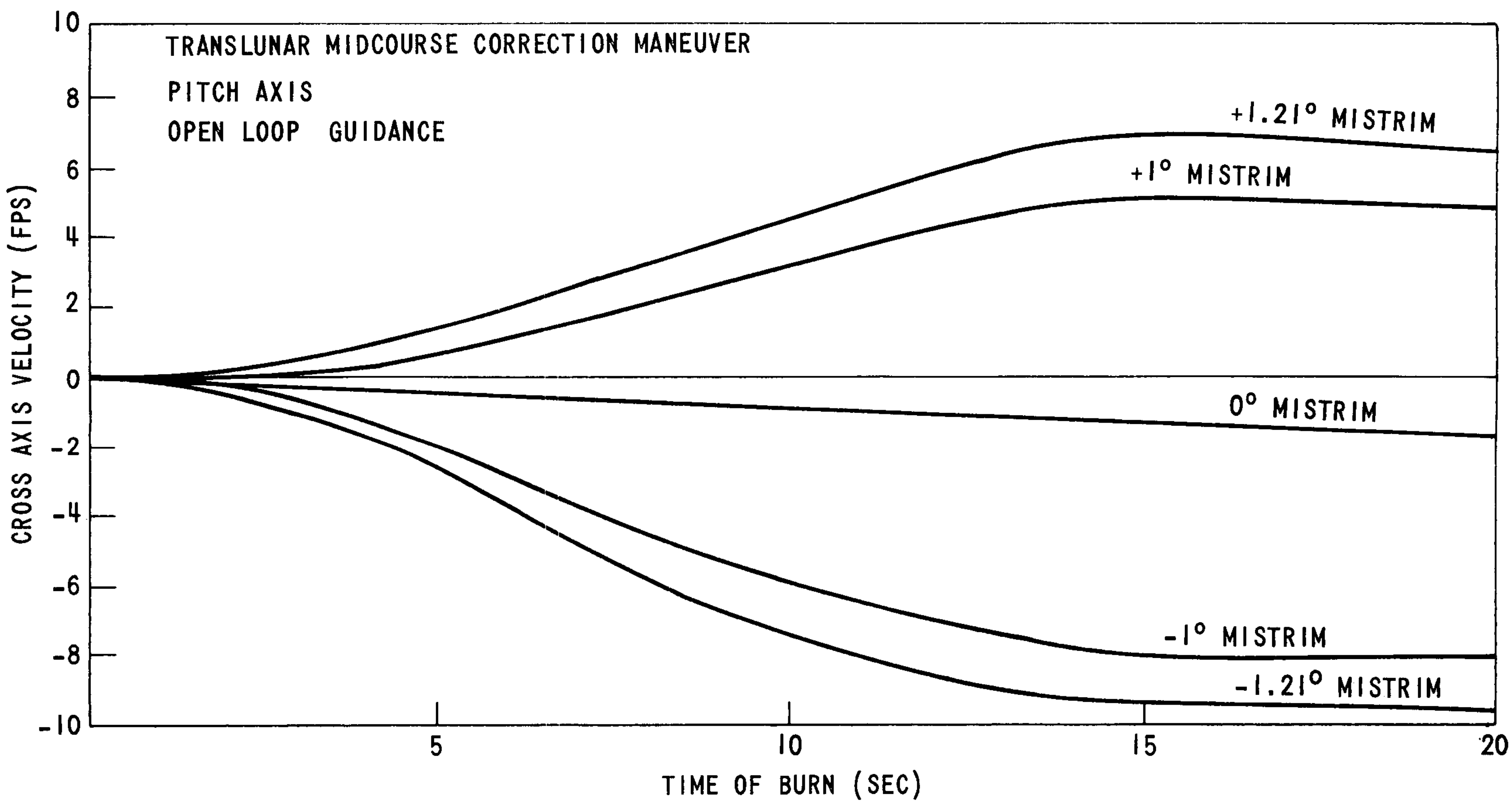
GRAPH I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PITCH AXIS
OPEN LOOP GUIDANCE
+1.21° MISTRIM
+1° MISTRIM
0° MISTRIM
-1° MISTRIM
-1.21° MISTRIM
CROSS AXIS VELOCITY (FPS)
TIME OF BURN (SEC)
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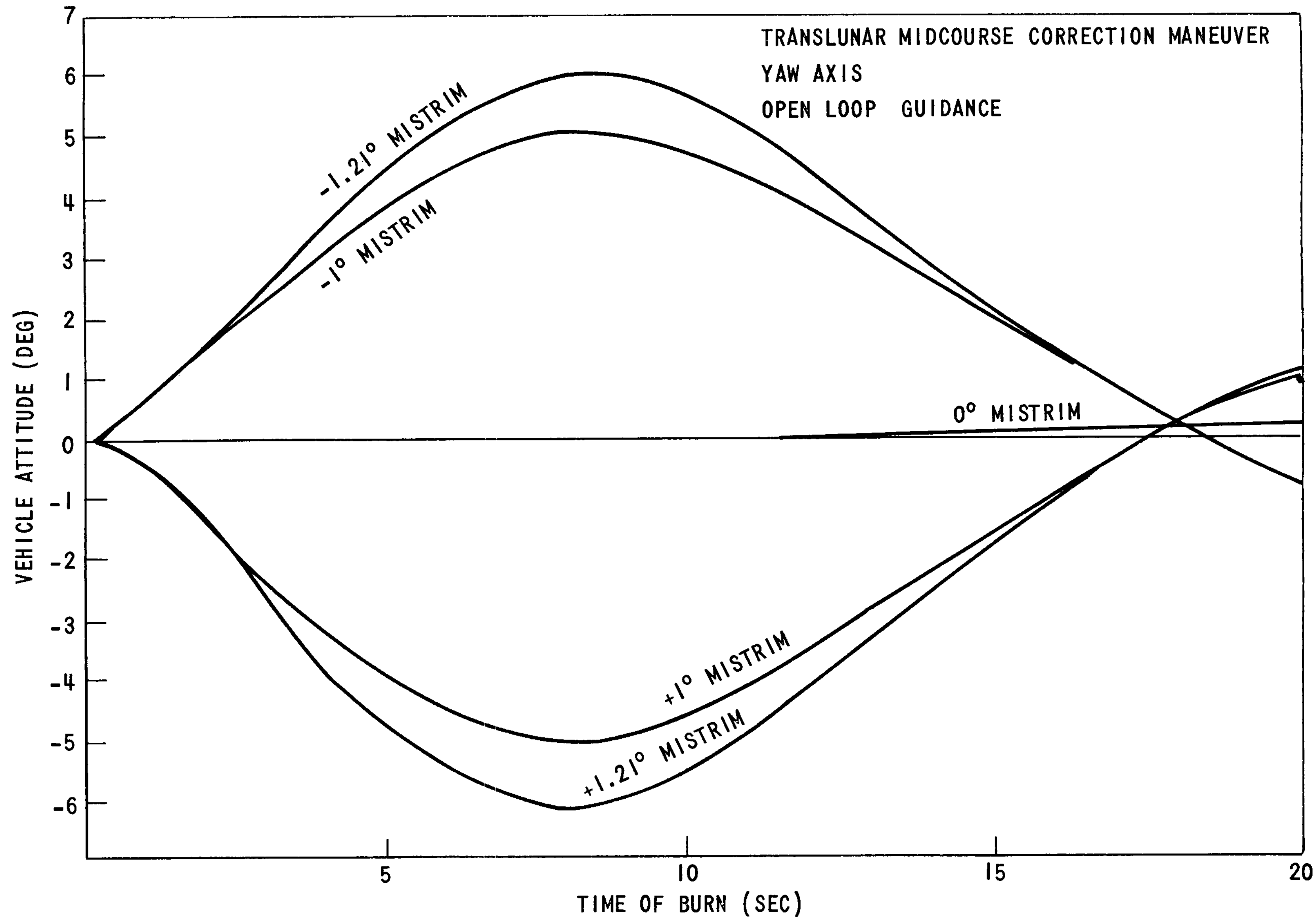
GRAPH 2



TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
YAW AXIS
OPEN LOOP GUIDANCE
-1.21° MISTRIM
-1° MISTRIM
0° MISTRIM
+1° MISTRIM
+1.21° MISTRIM
VEHICLE ATTITUDE (DEG)
TIME OF BURN (SEC)
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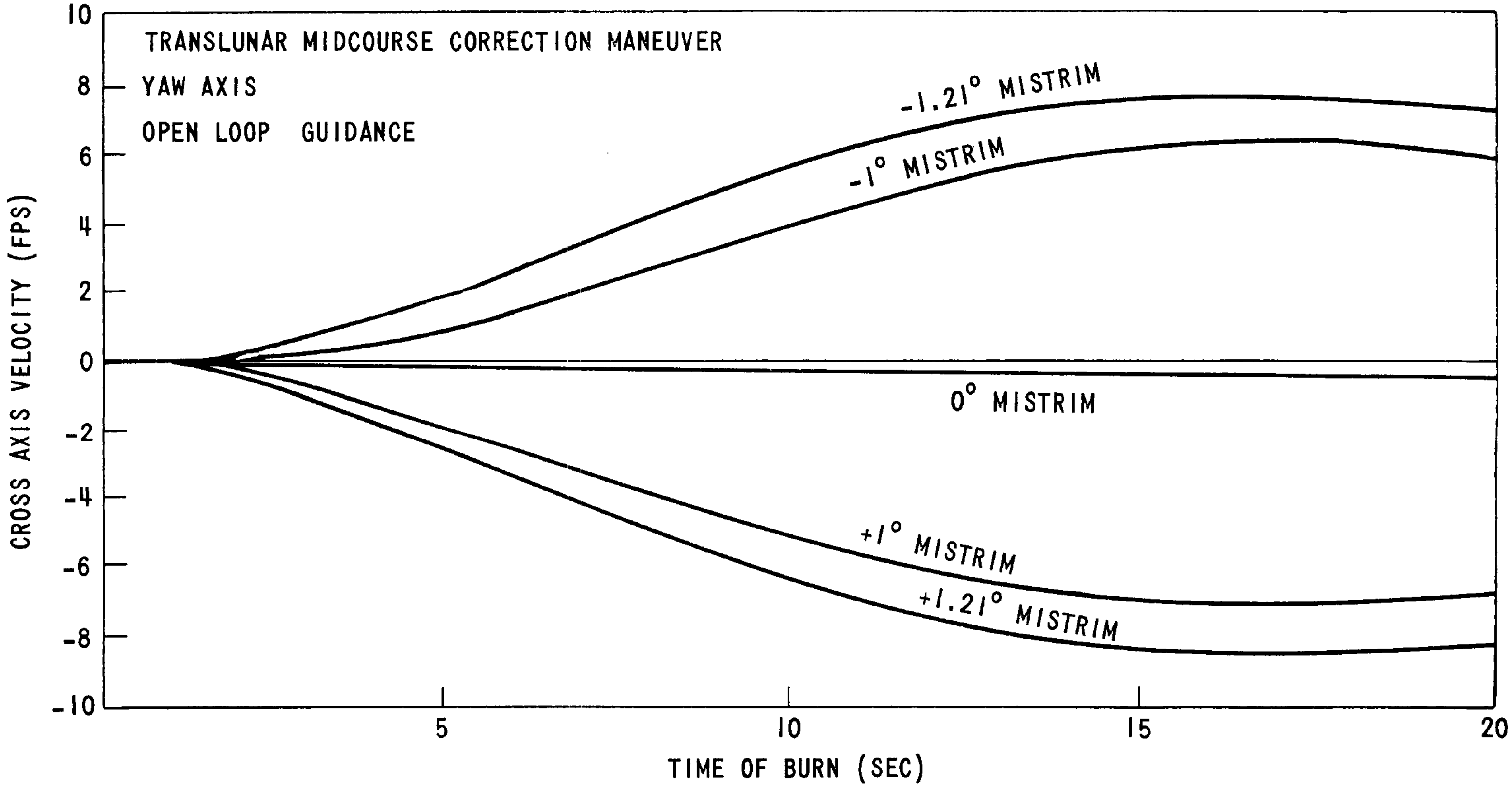
GRAPH 3


TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
YAW AXIS
OPEN LOOP GUIDANCE
-1.21° MISTRIM
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0° MISTRIM
+1° MISTRIM
+1.21° MISTRIM
CROSS AXIS VELOCITY (FPS)
TIME OF BURN (SEC)
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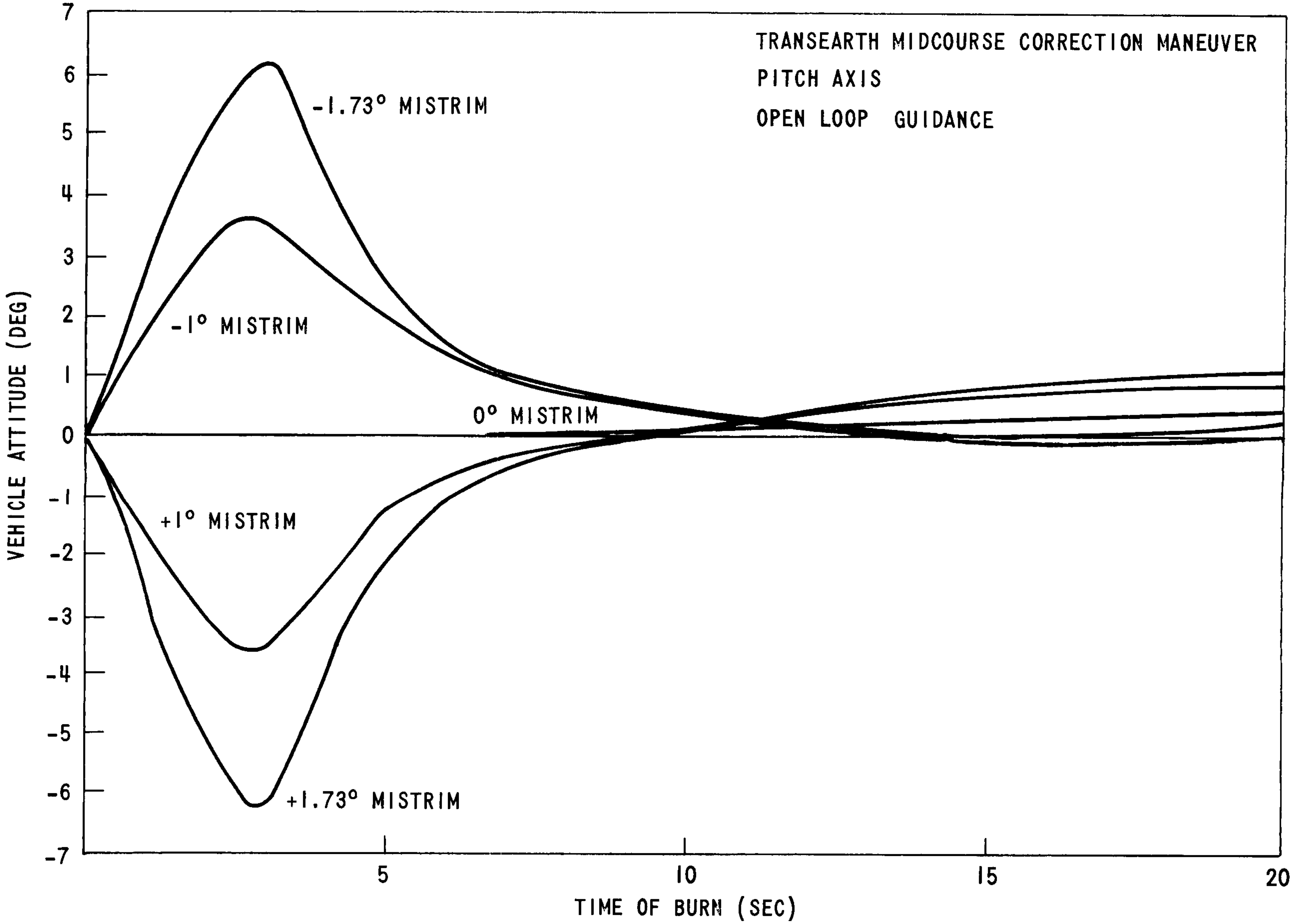
GRAPH 4


TRANSEARTH MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
OPEN LOOP GUIDANCE
-1.73° MISTRIM
-1° MISTRIM
0° MISTRIM
+1° MISTRIM
+1.73° MISTRIM
VEHICLE ATTITUDE (DEG)
TIME OF BURN (SEC)
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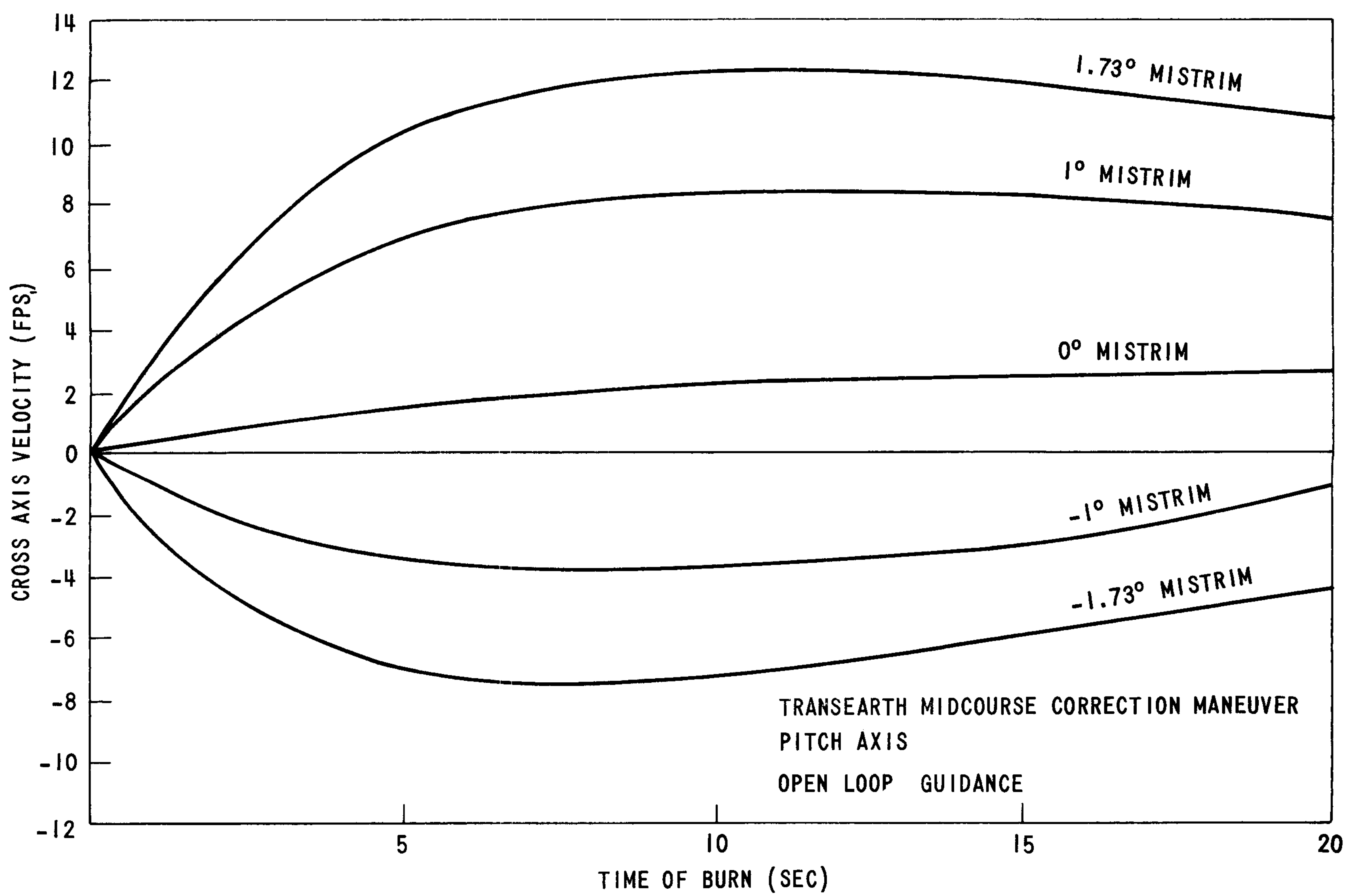
GRAPH 5


14
12
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-12
CROSS AXIS VELOCITY (FPS)
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20
TIME OF BURN (SEC)
1.73° MISTRIM
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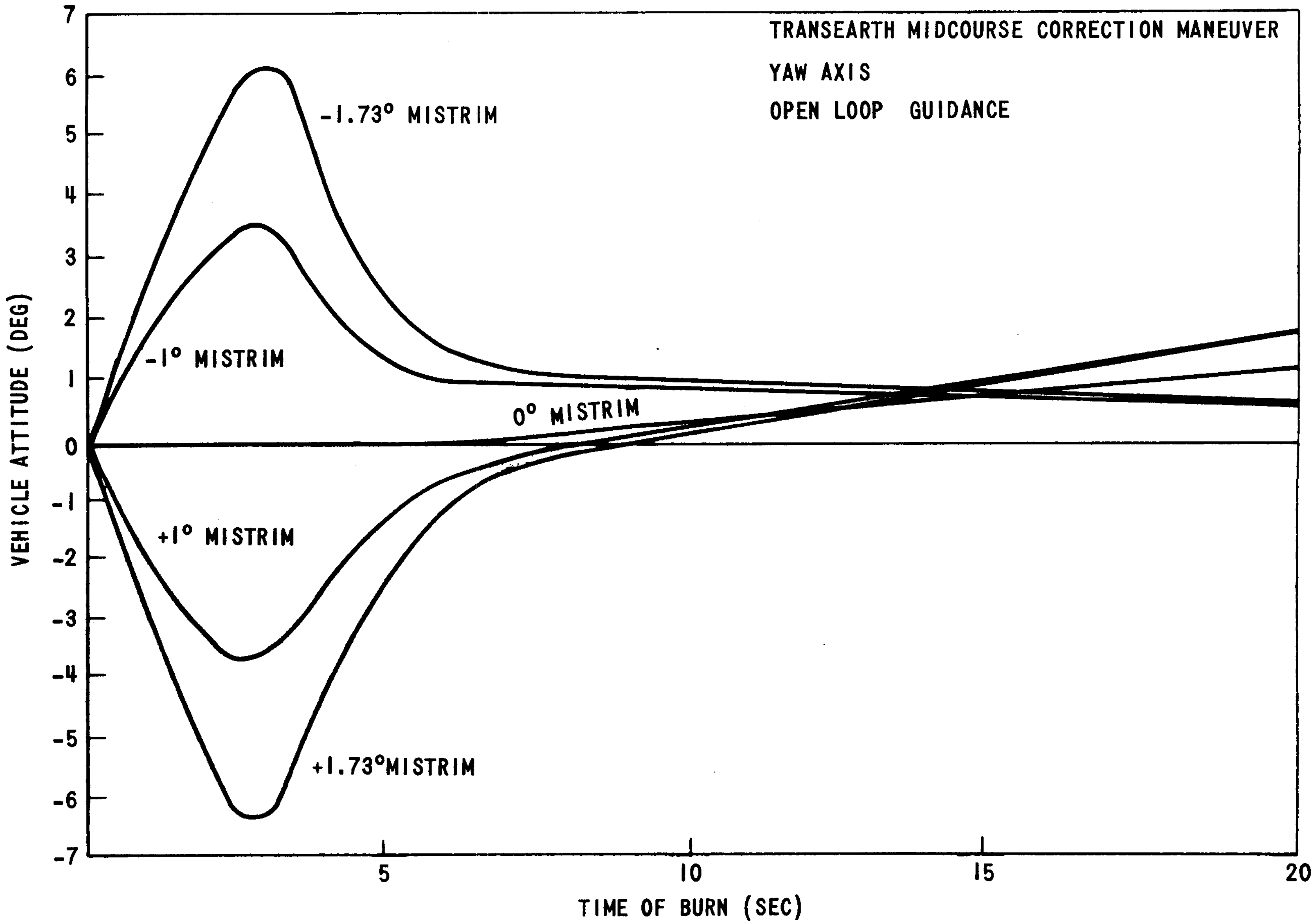
-1° MISTRIM
-1.73° MISTRIM
TRANSEARTH MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
OPEN LOOP GUIDANCE

GRAPH 6


TRANSEARTH MIDCOURSE CORRECTION MANEUVER
YAW AXIS
OPEN LOOP GUIDANCE
-1.73° MISTRIM
-1° MISTRIM
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+1.73°MISTRIM
VEHICLE ATTITUDE (DEG)
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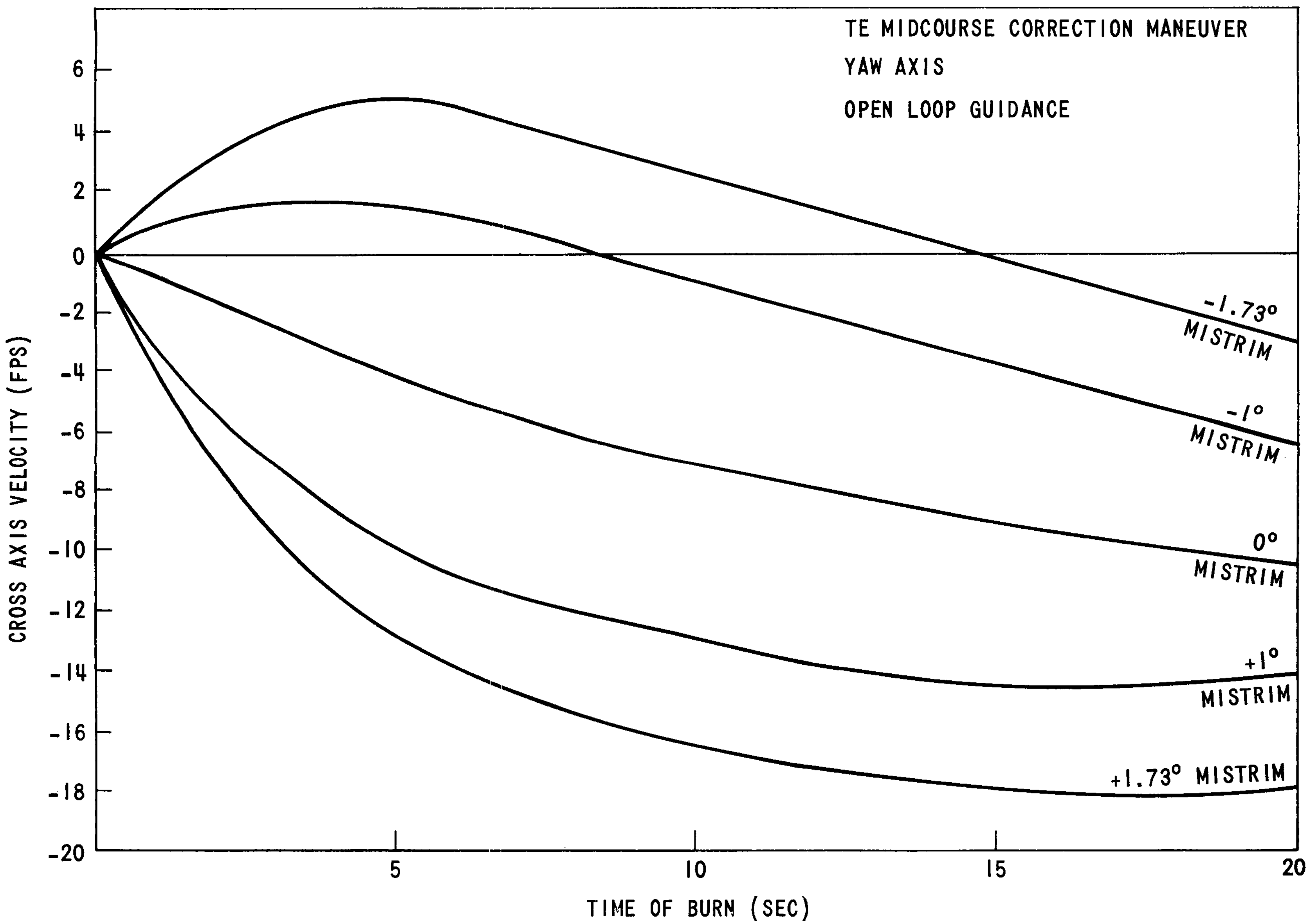
TIME OF BURN (SEC)

GRAPH 7



TE MIDCOURSE CORRECTION MANEUVER
YAW AXIS
OPEN LOOP GUIDANCE
CROSS AXIS VELOCITY (FPS)
TIME OF BURN (SEC)
-1.73° MISTRIM
-1° MISTRIM
0° MISTRIM
+1° MISTRIM
+1.73° MISTRIM
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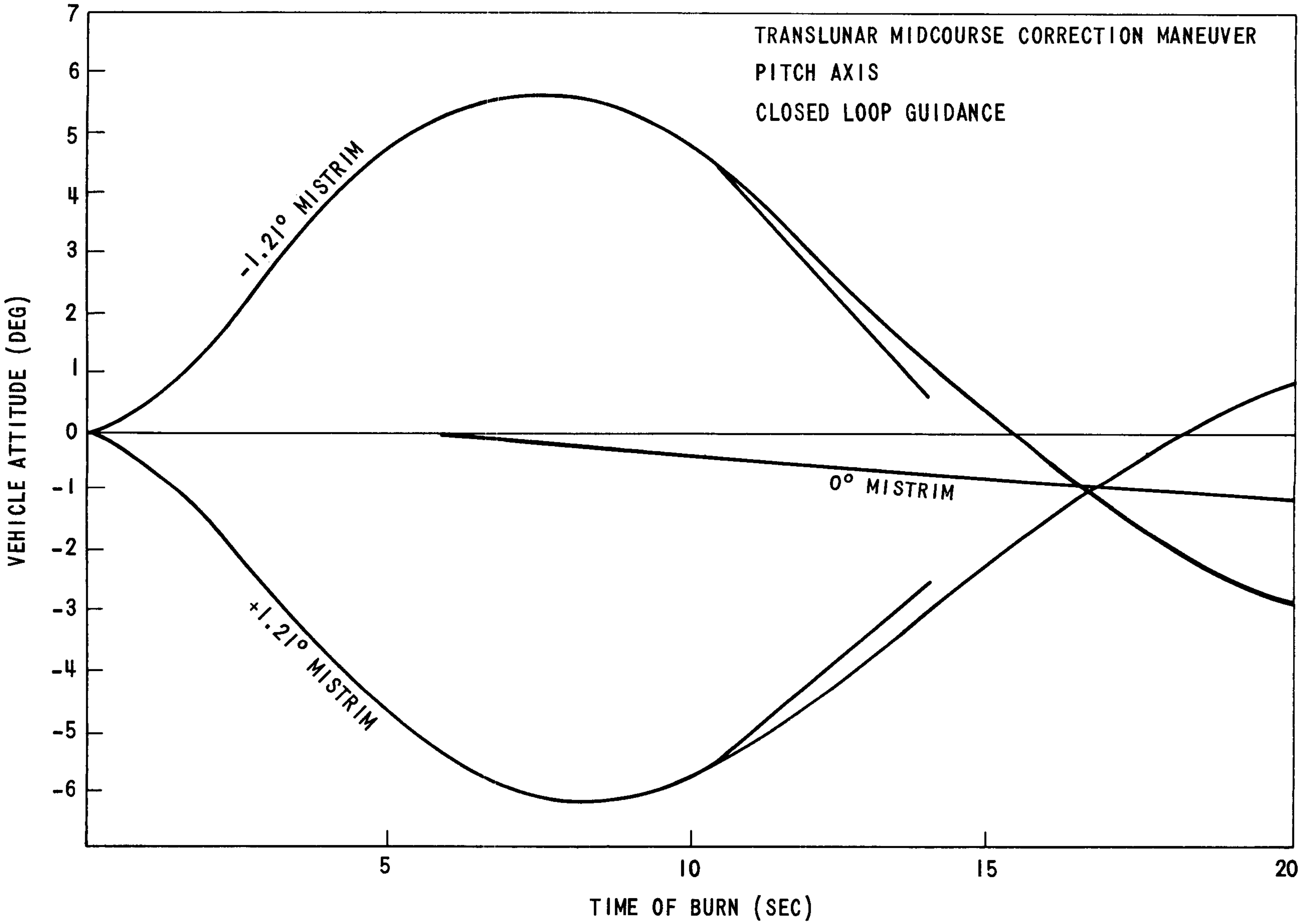
GRAPH 8


TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
CLOSED LOOP GUIDANCE
-1.21° MISTRIM
0° MISTRIM
+1.21° MISTRIM
VEHICLE ATTITUDE (DEG)
TIME OF BURN (SEC)
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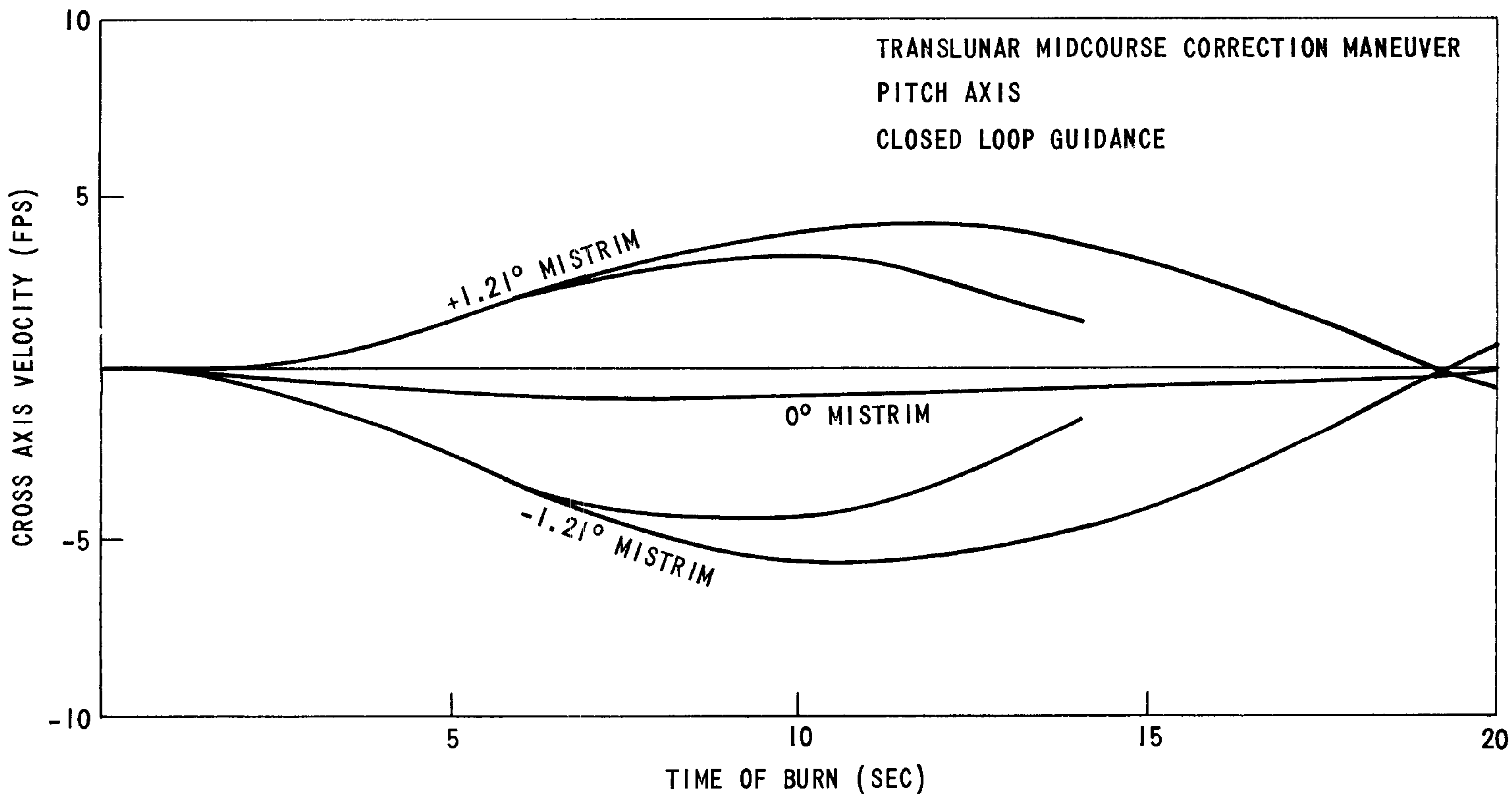
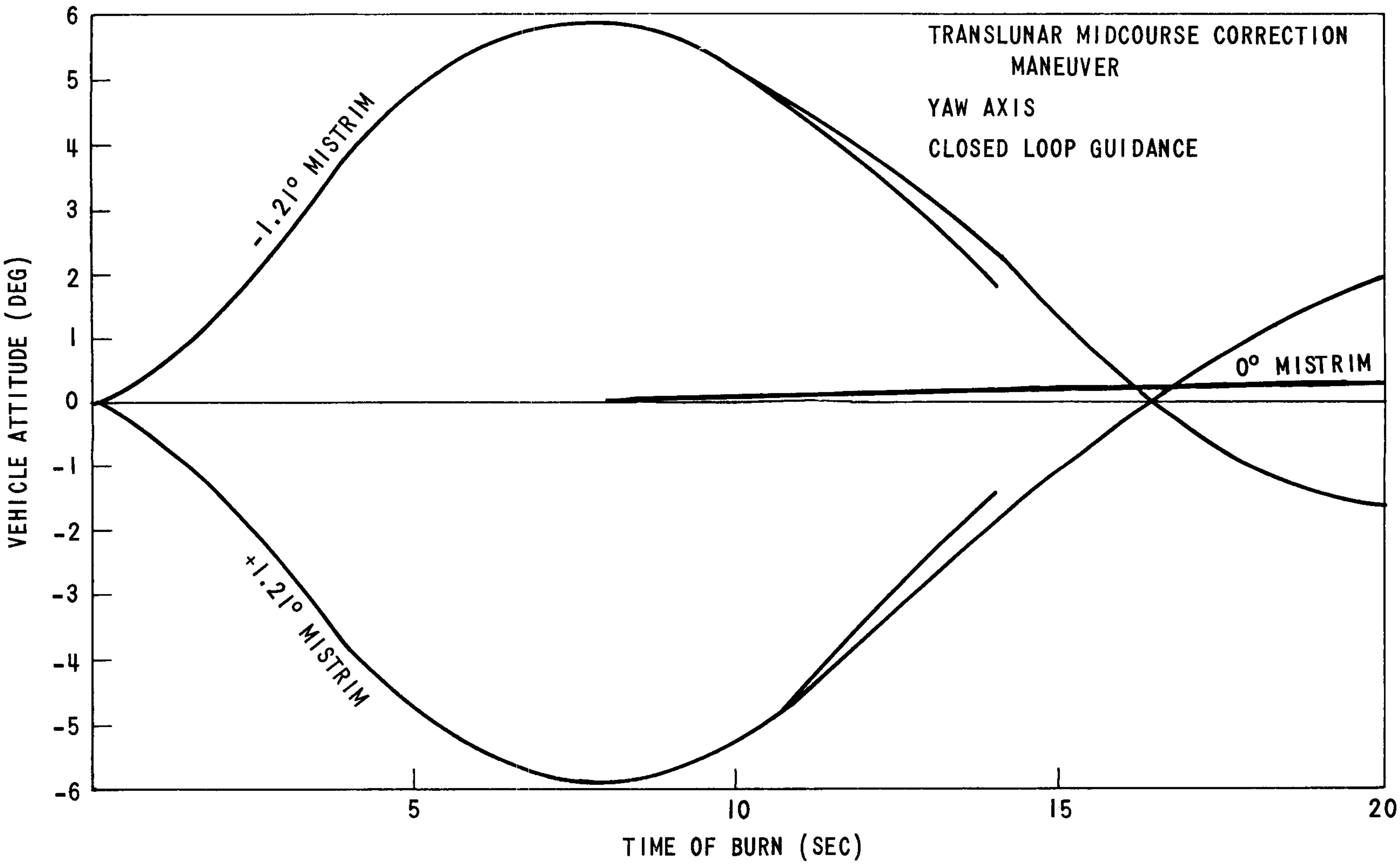
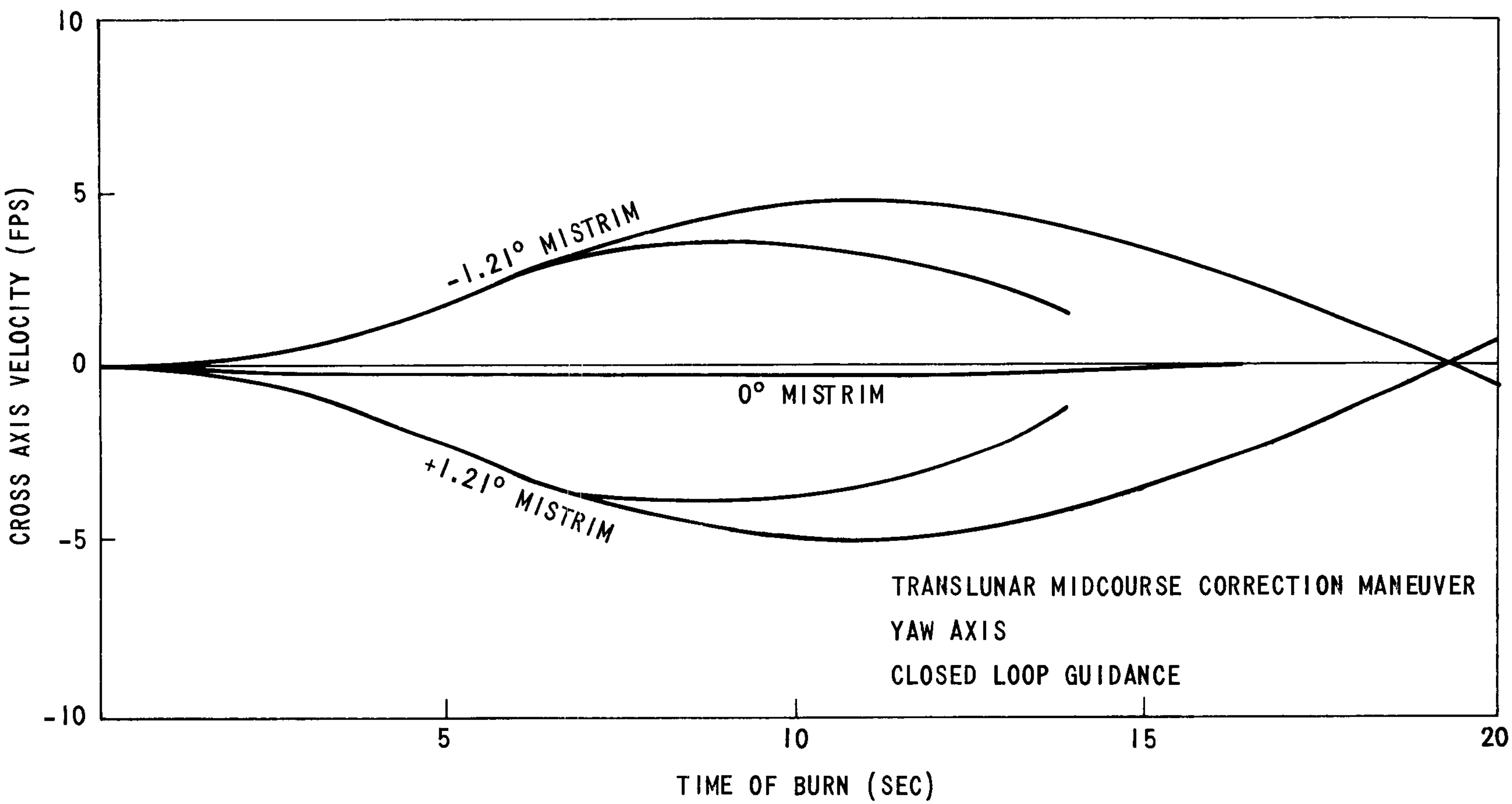
GRAPH 9


TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
CLOSED LOOP GUIDANCE
+1.21° MISTRIM
0° MISTRIM
-1.21° MISTRIM
CROSS AXIS VELOCITY (FPS)
10
5
-5
-10
5
10
15
20
TIME OF BURN (SEC)

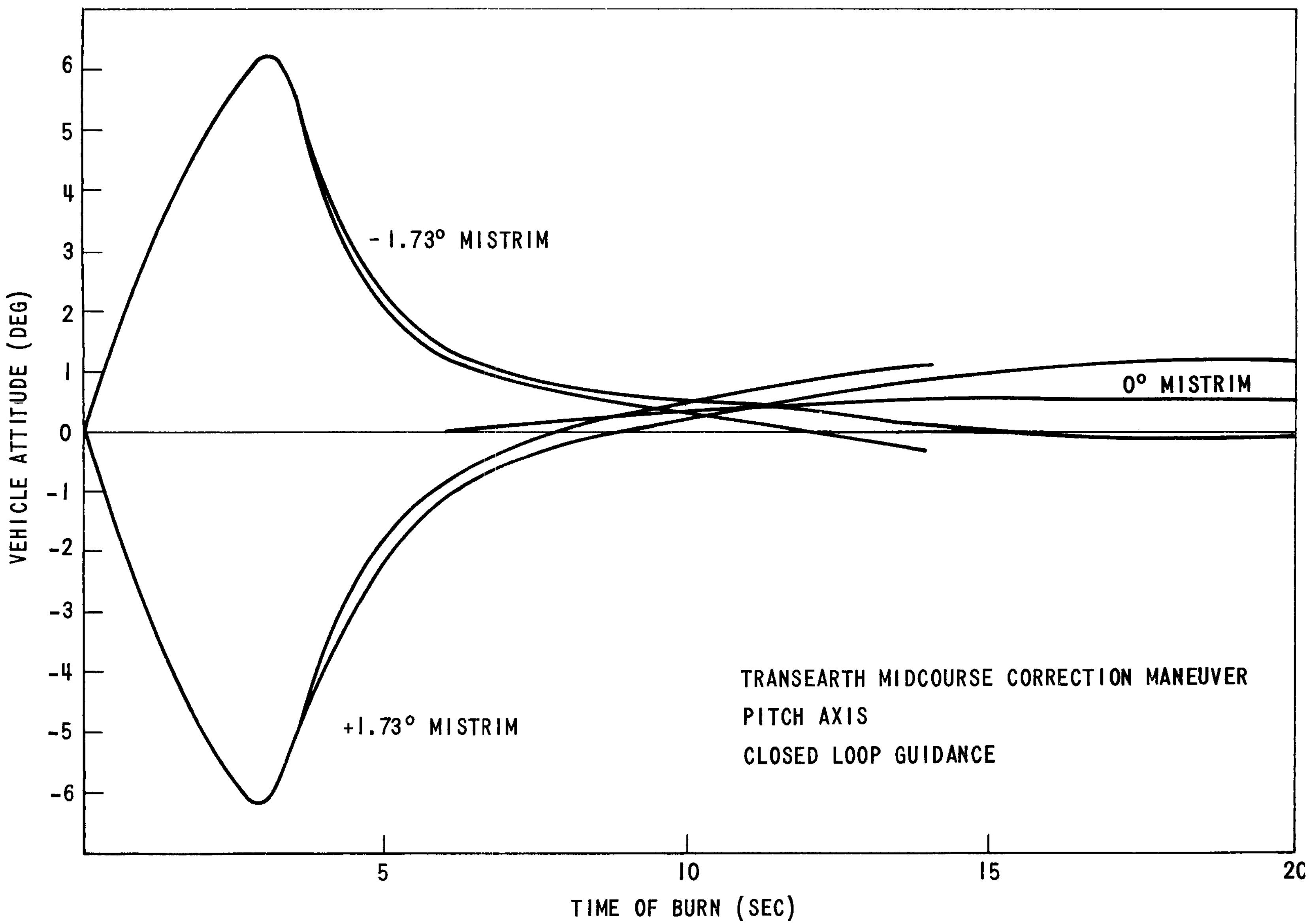
GRAPH 10


TRANSLUNAR MIDCOURSE CORRECTION
MANEUVER
YAW AXIS
CLOSED LOOP GUIDANCE
-1.21° MISTRIM
+1.21° MISTRIM
0° MISTRIM
VEHICLE ATTITUDE (DEG)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
5
10
15
20
TIME OF BURN (SEC)

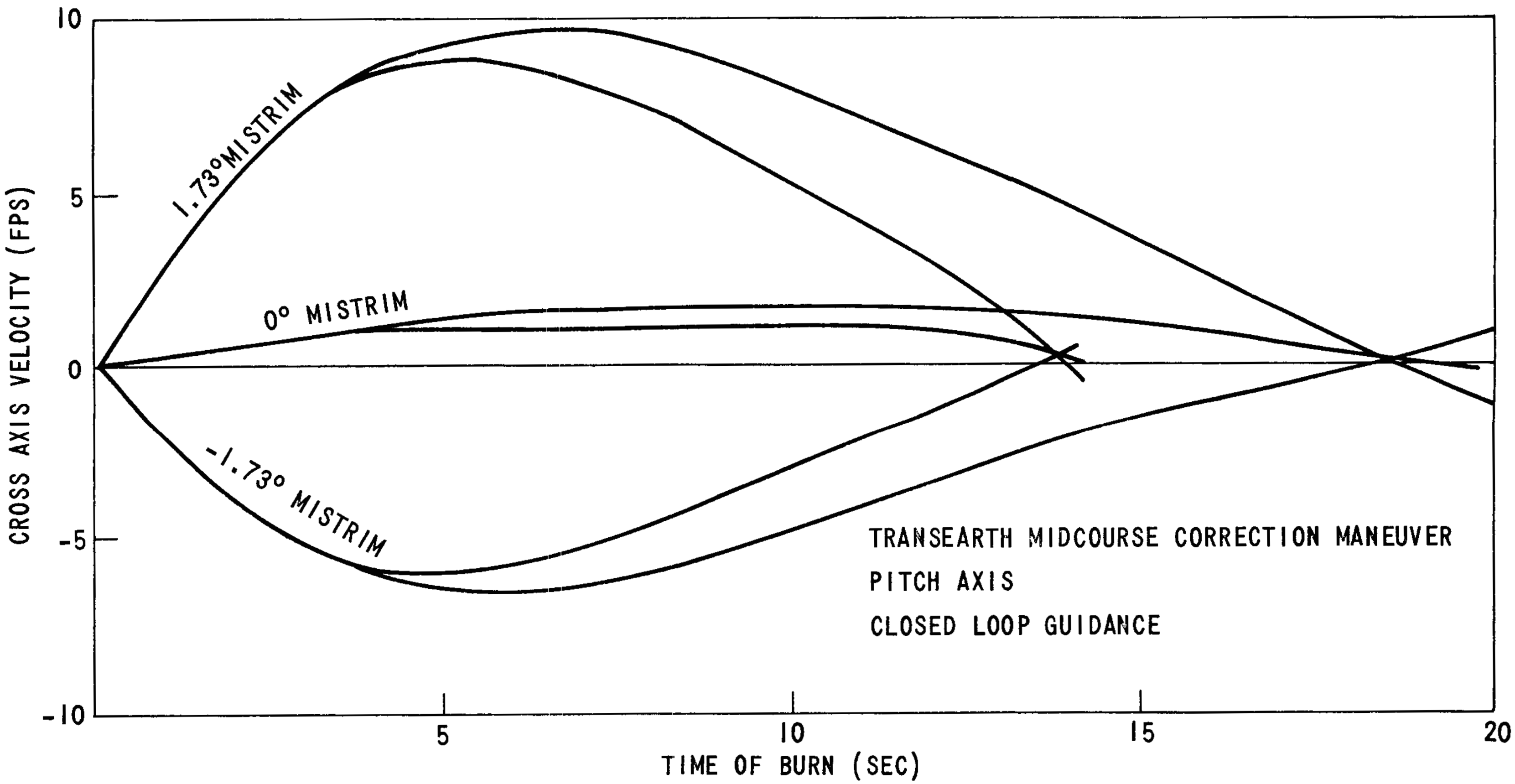
GRAPH 11


10
5
0
-5
-10
CROSS AXIS VELOCITY (FPS)
-1.21° MISTRIM
0° MISTRIM
+1.21° MISTRIM
TRANSLUNAR MIDCOURSE CORRECTION MANEUVER
YAW AXIS
CLOSED LOOP GUIDANCE
5
10
15
20
TIME OF BURN (SEC)

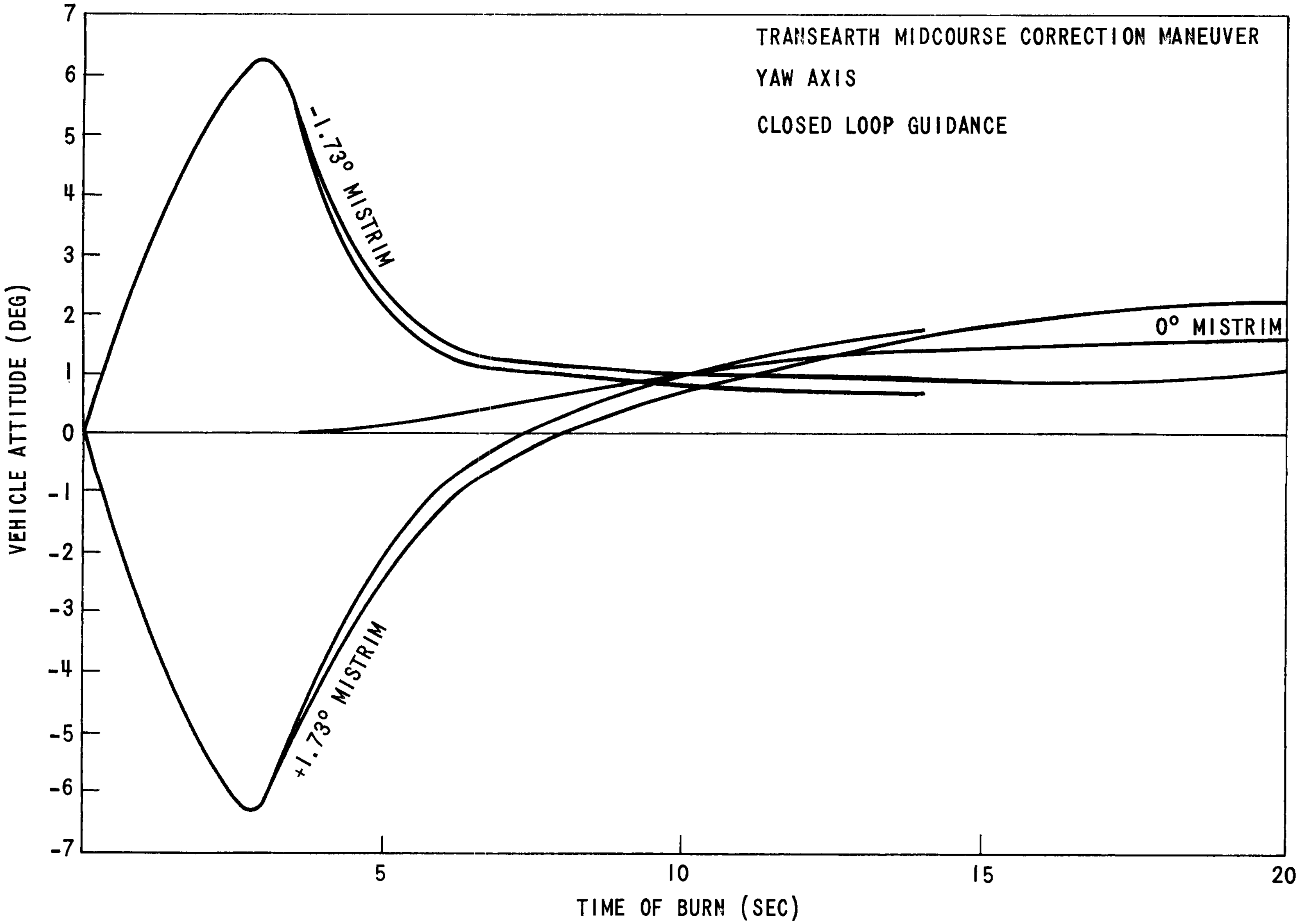
GRAPH 12


6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
VEHICLE ATTITUDE (DEG)
-1.73° MISTRIM
+1.73° MISTRIM
0° MISTRIM
TRANSEARTH MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
CLOSED LOOP GUIDANCE
5
10
15
20
TIME OF BURN (SEC)

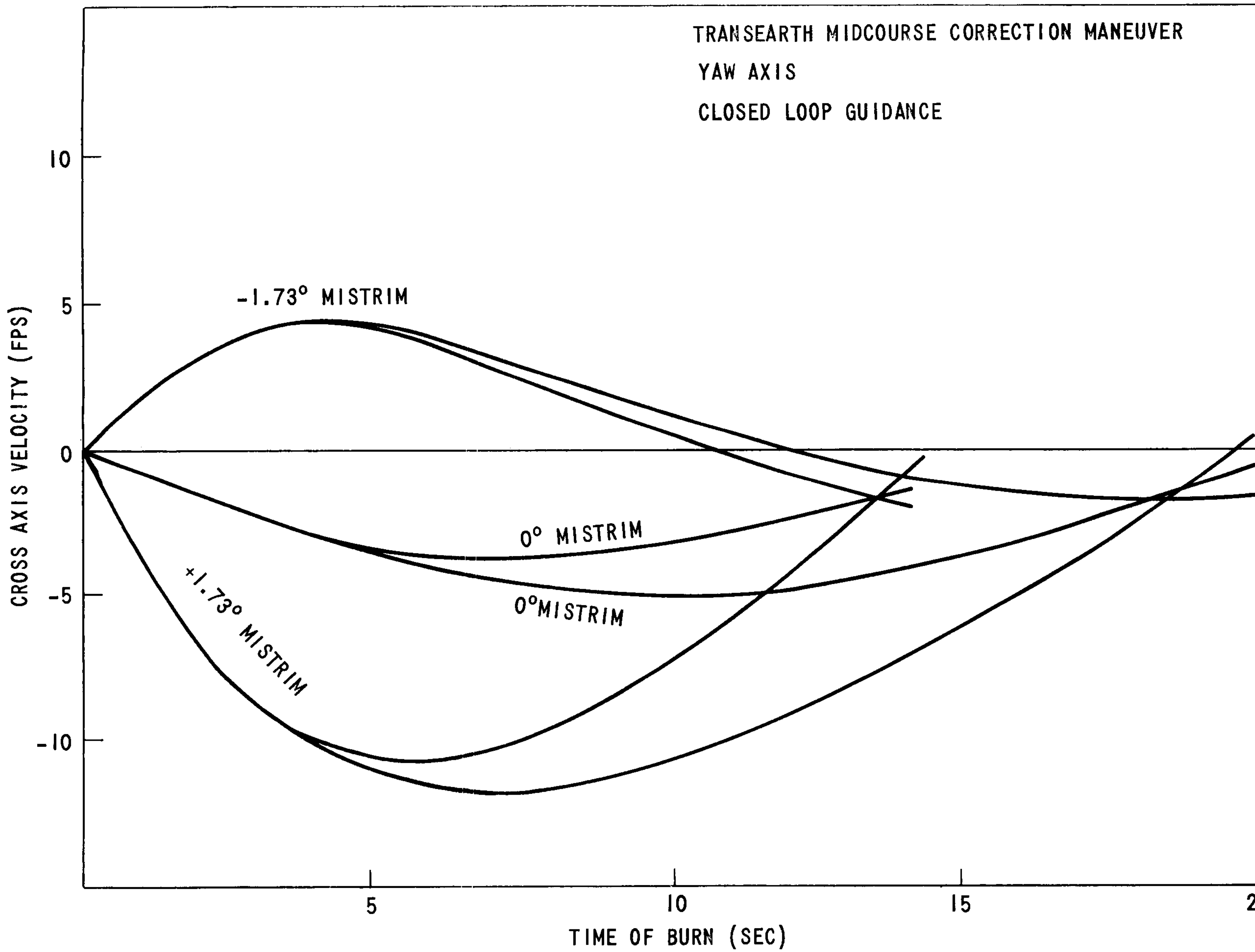
GRAPH 13


10
5
0
-5
-10
CROSS AXIS VELOCITY (FPS)
1.73°MISTRIM
0° MISTRIM
-1.73° MISTRIM
TRANSEARTH MIDCOURSE CORRECTION MANEUVER
PITCH AXIS
CLOSED LOOP GUIDANCE
5
10
15
20
TIME OF BURN (SEC)

GRAPH 14


TRANSEARTH MIDCOURSE CORRECTION MANEUVER
YAW AXIS
CLOSED LOOP GUIDANCE
-1.73° MISTRIM
+1.73° MISTRIM
0° MISTRIM
VEHICLE ATTITUDE (DEG)
TIME OF BURN (SEC)
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
5
10
15
20

GRAPH 15


TRANSEARTH MIDCOURSE CORRECTION MANEUVER
YAW AXIS
CLOSED LOOP GUIDANCE
-1.73° MISTRIM
0° MISTRIM
0°MISTRIM
+1.73° MISTRIM
CROSS AXIS VELOCITY (FPS)
10
5
0
-5
-10
5
10
15
20
TIME OF BURN (SEC)

GRAPH 16

BELLCOMM, INC.

Subject: Initial Thrust Mistrim and c.g. Motion Effects on Translunar and Transearth Midcourse Correction Maneuvers - Case 310

From: F. La Piana

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